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GRB 110715A: Multifrequency study of the first gamma-ray burst observed with ALMA

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Abstract

GRB 110715A had a bright afterglow that was obscured by a high Galactic extinction. We discovered the submillimetre counterpart with APEX and followed it in radio with ATCA for over 2 months. Additional submillimetre observations were performed with ALMA as a test of the ToO procedures during commissioning. UV, optical and NIR observations were performed with UVOT/Swift and GROND at the 2.2 m telescope in La Silla and X-ray data was obtained by XRT/Swift. The dataset is complemented with spectroscopic data from the X-shooter spectrograph at the VLT. From a broadband model we derive a peculiar density profile in the environment of the progenitor, with a discontinuity that produces a break in the light curve at ~ 1 day after the burst onset. The absorption features present in the intermediate resolution optical/nIR spectra reveal a redshift of 0.8224 and a host galaxy environment with low ionisation and no velocity components beyond 30 km s^{-1}. These preliminary results will be published elsewhere [18].

1 Introduction

Gamma-ray bursts [13] are the most violent explosions in the Universe. They are normally classified in two types based on their duration: short GRBs ($T_{90} < 2$ s) and long GRBs ($T_{90} > 2$ s) [14]. Soon, it was also known there is a correlation between short duration with a hard spectrum and negative/negligible spectral lags and long duration with a soft spectrum and high spectral lags [15].

GRBs prompt emission can be modelled as originating from either internal shocks or the photosphere or magnetic dissipation of a magnetically dominated jet. In turn, afterglow emission originates from external shocks of the jet against the interstellar medium (ISM), and includes forward and maybe reverse shock components [19, 20]. This afterglow shows a synchrotron emission that is characterised by its spectral slopes and break frequencies. Determining the spectral slopes and localising the characteristic frequencies and their evolution allows us to derive the micro- and macro-physical parameters of the GRB ejecta and its environment, which include the total energy, the density of the environment, the energy in magnetic and electric fields, the geometry of the explosion, etc. In order to test the fireball model and estimate its free parameters, thus allowing us to characterise the physics behind these extreme phenomena, multi-wavelength observations are needed. The millimetre/submillimetre range, is one of the most important ones to constrain the afterglow models, as it is where the flux density of the emission reaches its peak. In this range the new ALMA observatory will bring an important leap forward thanks to its great improvement in resolution and sensitivity in comparison with previous observatories.

It is still unclear what is progenitor's nature of short bursts, but anyway it's commonly considered they are produced by the merger of binary compact stars (either NS-NS or BH-NS systems). It makes them the most promising tool to detect gravitational waves. On the opposite side, it is better established that long GRBs are due to death of massive stars [12, 25], probably high rotating Wolf-Rayet type [1], but it remains unclear what is the specific mechanism in the core collapse process that triggers the formation of a jet.

These special phenomena can be used as powerful tracers of star-forming galaxies from $z = 0.08$ (GRB 980425A, [7]) to $z = 8.2$ (redshift spectroscopically confirmed [23, 17], a photometric $z = 9.4$ is given by [2] to GRB 090429B) due to short life periods known for such stars.

GRBs can also be used to find out region properties around the progenitor and many intervening systems in the sight of view crossed by the jet doing optical/NIR spectroscopy. Its strength resides in the extremely brightness afterglow, making possible to measure the signature of the host's ISM from atomic state transitions, even when the galaxy is not directly detected (e.g. the burst focus of this work).

2 Observations

GRB 110715A was an intense burst, discovered [21] by the Burst Alert Telescope (BAT) onboard the *Swift* mission [8], and also observed by *INTEGRAL*/SPI-ACS [22], *Konus*/WIND

[9] and *Suzaku*/WAM [16]. It was classified as a long burst, with a duration ranging from 8 to 20 seconds in the different satellites, depending on the energy coverage and sensitivity of each instrument.

The burst happened at a galactic latitude of only 6 degrees, implying that it was optically obscured by dust from the Milky Way ($E_{B-V} = 0.59$), which complicated the optical follow-up. In spite of this, it was detected by the Ultra Violet/Optical Telescope (UVOT) on *Swift* just a few minutes after the gamma emission. This implied that the intrinsic luminosity of the event was high. In view of this, we triggered our target of opportunity programme at the 12 m Atacama Pathfinder EXperiment (APEX), using the LABOCA instrument to observe in 850 μm. Observations were performed 1.42 days after the GRB onset, and we discovered a bright submillimetre counterpart, with an intensity of 10.4 ± 2.4 mJy, making it the fourth brightest GRB ever observed in these wavelengths.

As a test of the target of opportunity procedure, GRB 110715A was subsequently observed at Atacama Large Millimeter Array (ALMA), in what became the first observation of a GRB by this observatory. The ALMA Science Team report a preliminary detection from a test observation of this source of 4.9 ± 0.6 mJy at 345 GHz after 25 mins on source with 7 antennas 3.6 after the onset. The centroid of the ALMA position is 15:50:44.05 −46:14:06.54 with an uncertainty of $0.''3 \times 0.''1$ at a position angle of 76 degrees, which is the most precise localisation of the event to date.

Following the detection of the afterglow at submm wavelengths with APEX, radio observations of were taken with the Australia Telescope Compact Array (ATCA [24]) two and three days after the outburst. These observations resulted in further detections of the afterglow at 44 GHz [11]. Further observations were obtained up to 75 days post burst at 44, 18, 9, and 5 GHz.

We obtained follow-up observations of the optical/NIR afterglow of GRB 110715A with the seven-channel imager GROND [10] mounted on the 2.2 m MPI/ESO telescope stationed in La Silla, Chile. The afterglow is detected in all g, r, i, z, J, H and K filters between 2.5 and 8 days.

For the study of the X-ray emission, we made use of the *Swift*/XRT publicly available data [6]. All the photometric observations are compiled in the form of a multi-band light curve in Fig. 1.

The dataset is completed with a spectrum obtained with the X-shooter spectrograph at the Very Large Telescope, in Paranal Observatory (Chile), 12.7 hours after the GRB. The spectrum covers the complete range between 3000 and 24800 Å, although the strong optical extinction only allows detection above ∼3600 Å.

3 Results

We detect six absorption lines in the complete spectrum that we identify as MgI, MgII, CaI and CaII at a common redshift of 0.8224 ± 0.0002. We have measured equivalent widths of these lines and limits for several others using a self-developed code. Following the prescription of [5], we obtain a line strength parameter for GRB 110715A of $LSP = -0.42$, implying that

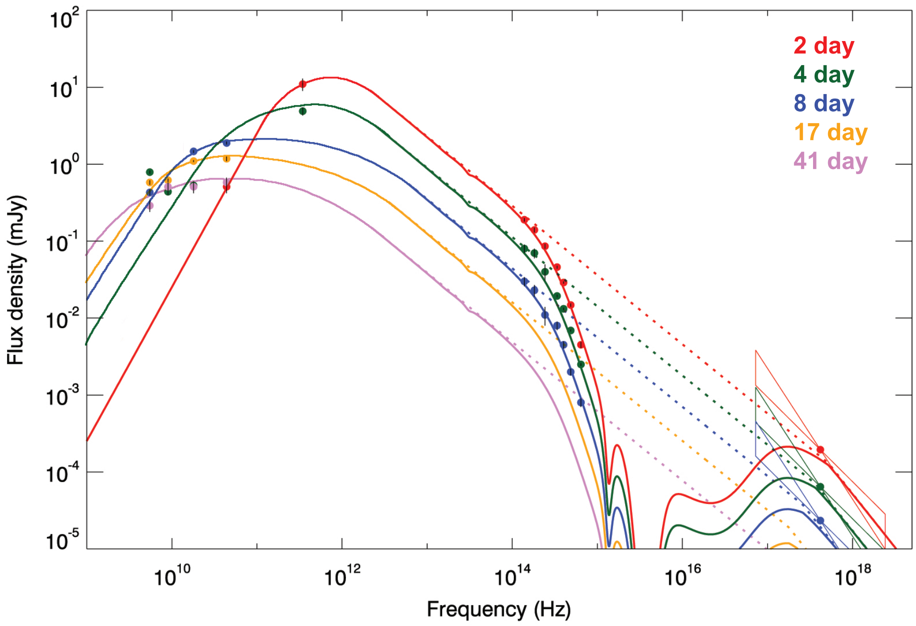

Figure 1: Afterglow light curve of the 17 observed bands.

this event is in the percentile 29 of line strengths, indicating a lower than average column density of material in the line of sight. This can point towards a small host galaxy. This is consistent with the fact that there are no velocity components in the absorption features faster than 30 km s^{-1}.

Studying the evolution of the 17 bands, from radio to X-rays in which we have photometric information, we have attempted to fit a model that describes the behaviour of the afterglow. A first approximation to the evolution of the spectral energy distribution of the afterglow his shown in Fig. 2. The best fit is obtained with a fireball model with a varying density profile in the environment that surrounds the progenitor, evolving from $n(r) \propto r^{-0.6\pm0.1}$ during the first day to $n(r) \propto r^{-2.5\pm0.1}$ afterwards.

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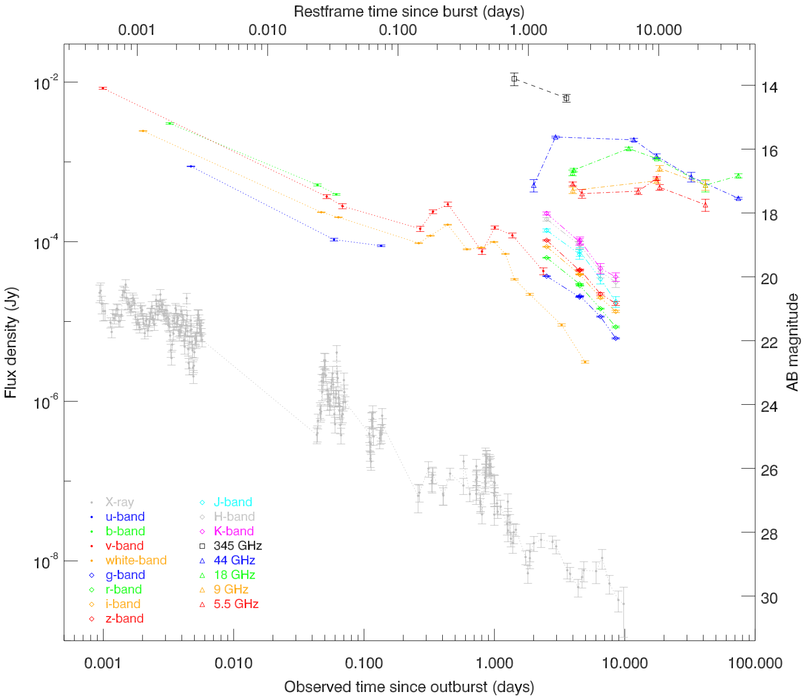

Figure 2: Evolution of the spectral energy distribution of the GRB afterglow from radio to X-rays.

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